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EXERCISE THERMOREGULATION AFTER PHYSICAL TRAINING IN WARM AND TEMPERATE ENVIRONMENTS[1]

by

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The main aim of studies was to evaluate the effect of ten days exercise training (ET) and exercise-thermal training (ETT) on the level of thermoregulatory reactions during control long lasting exercise test (CET) and standard exercise test (ST) by which the values of maximum oxygen uptake (VO_2 max) were estimated.

Ten men were taken as subjects. The other ten were controls (without physical training).

The experimental approach resulted from the hypothesis that the same value of thermal stimulus i.e. the equal change in rectal temperature will cause the same effect in exercise thermoregulatory reactions. In ET each training unit lasted 90 mins and and the level of Tre at the end of that exercise were taken as a criterion for the duration of the period of ETT training. Therefore in ETT training procedure the training units were shorter because the same rectal temperature increase were achieved earlier than during ET.

The following physiological indices: oxygen uptake (VO_2), rectal (Tre), muscle (Tmusc.), and skin (Tsk) temperatures, level of dehydration (%DBwt), sweating rate (SR), plasma volume changes (%DPV) and haematocrit (Hct) in the course of CET as well as maximum oxygen uptake during ST were analysed.

The obtained results have shown that both the ET and ETT training programmes improved the efficiency of exercise thermoregulation however the ETT training with shorter training units gave the very similar results in exercise thermoregulation as the exercise training program, but is more sparing in utilisation of energy sources.

Key words: exercise thermoregulation, physical training, haematocrit, rectal, muscle and vastus lateralis temperatures.

Introduction

Some studies (Inbar et al. 1981, Kubica et al. 1986, Kruk et al. 1990) have shown an improvement of exercise thermoregulatory responses following physical training in room temperature. Other authors suggested however, that the acclimation

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to heat stress can be developed only when the subject exercises during the heat exposure (Gisolfi et al. 1969, Kubica et al. 1986). In one of our former paper the profitable effect of passive heating in sauna on exercise thermoregulation was confirmed (Tyka et al. 1996).

It seems to be valid to identify an optimal, simple procedure to improve temperature regulation during physical exertion especially of long duration.

This might of great importance for endurance runners or players indifferent sport events. This study was undertaken to compare the effects on exercise thermoregulatory responses of two physical training programs in thermoneutral and warm environments. Recently the study of one prewarming in cold season on thermoregulatory responses during exercise was applied (Torii et al. 1996) and the improvement of thermoregulation was found out.

The experimental approach resulted from the hypotesis that the same value of thermal stimulus i.e. the change of rectal temperature of the same order, will evoke the similar training effect in thermoregulatory responses. If it is true the achievement of the similar enhancement of thermoregulatory changes in exercise-thermal training will be possible owing to the shorter exercise session saving the energy stores of the body.

Material and methods

Twenty men being volunteers were taken as subject (Tab.1). Ten of them, selected spontaneously were required to participate in two kinds of physical training. Other ten students were controls (without physical training).

Both training procedures consist of 10 exercise units accomplished on separate, consecutive days. In the first training procedure (exercise training – ET) each unit consisted of 90 mins exercise with relative intensity of 56% ± 2% of maximal O_2 uptake ($VO_{2\ max}$), performed on bicycle ergometer. It was held at room temperature – 21° ± 2°C and 50% ± 5% relative humidity.

In the second training procedure (exercise – thermal – ETT) ambient conditions were kept at 33°C ± 1°C and 50 ± 5% relative humidity. The duration of each exer-

Table 1. Morphological indices of the subjects in two groups studied. The difference between mean values were statistically insignificant

Groups	Age (years)	Height (cm)	Weight (kg)	Body Surface Area BSA (m^2)
Control				
x	22.3	154.6	67.44	1.75
SD	1.16	4.54	4.51	0.07
Training				
x	23.2	177.7	72.09	1.89
SD	1.62	5.12	6.07	0.09

cise training unit was varied among individuals ranging from 20 to 40 minutes. This was determined so that the increase in rectal temperature (Tre) will be to that observed in the ET training procedure at 21°C. The relative intensity was the same as during first procedure i.e. 56% of $VO_{2\ max.}$

Between the two training program one month interval was applied.

Before and after the completion of both 10–days training procedure a prolonged cycle lasting 90 minutes was performed at a relative intensity of 56% ± 2% of VO_2 max (Fig.1). This exercise done in room temperature was assumed as control exercise test (CET I – before and CET II – after training period). It was performed after light breakfast, still in the same time of day because the circadian influence was confirmed formerly.

The sequence of measurements are shown on Figure 1.

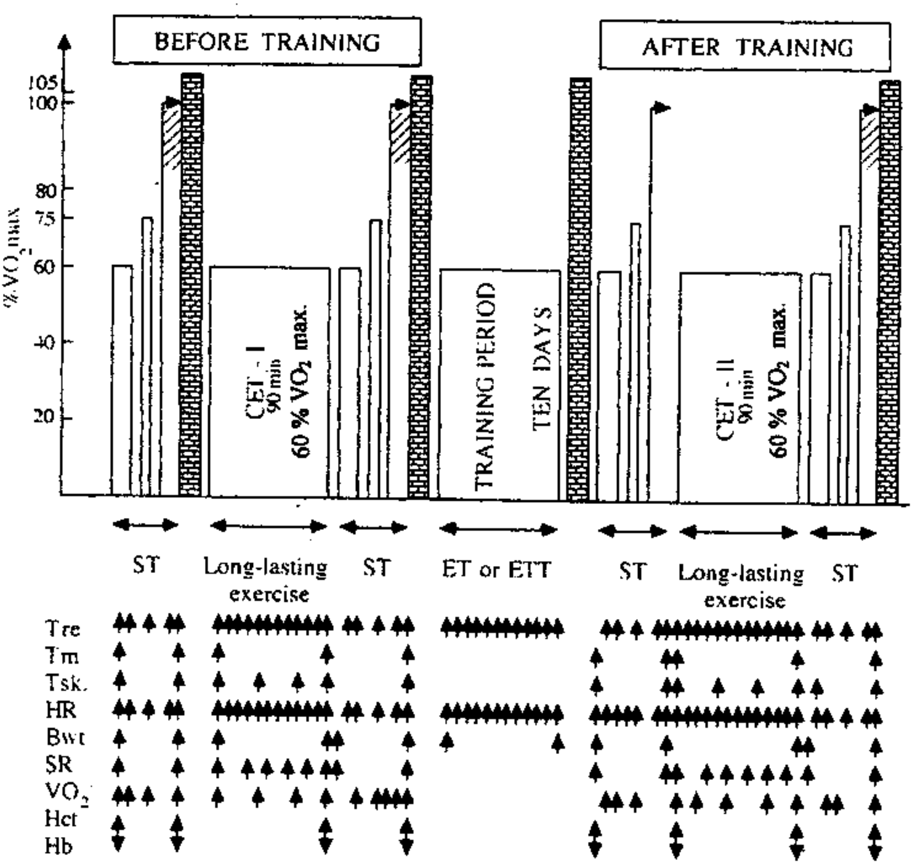

Figure 1. Procedure and sequence of measurements taken during the experiments CET — Control Exercise Test

Maximum oxygen uptake was determined before and after studies (training – ET and ETT procedures or control group) according to Nielsen et al. (1982) in graded exercise (ST). Minute oxygen uptake at rest and during exercise was evaluated using the Beckman MMC. Rectal temperature – at depth of 15 cm, muscle vastus lateralis temperature (Tmusc) – at depth of 2.5 cm and skin temperatures (Ts) in seven points according to Hardy and DuBois (1938) were measured by means of Ellab electrothermometer and heart rate (HR) was monitored by one–channel electrocardiograph.

The level of dehydration was determined, based on body weight changes with accuracy of ±50 g. Sweating rate (SR) on the skin area below scapula was evaluated according to method of Allen and Wilson (1971). Blood haemoglobin by means of cyanomethemoglobin method (Drabkin,s method) and haematocrite by haematocrite micro-centrifuge were evaluated. Plasma volume changes (%DPV) were calculated from haematocrit and haemoglobin concentration changes according to the formula proposed by Dill and Costill (1974). Blood samples were drawn from the antecubital vein before and after the completion of control exercise test.

In addition, the control group, had the same diet and schedule of academic work, etc. As compared to the basic group. They were only required to perform the described CET – Control Exercise Test twice, separated by ten days.

Results

The differences of all morphological indices were 1.e. age, body height, body weight and body surface area (BSA) statistically insignificant between training and control groups (Table 1).

The mean values of maximum oxygen uptake (VO_2 max) in both procedures were a little higher after the training period as compared to the initial levels (Table 2). In the control group $VO_{2\ max}$ values was lowered a little after ten days interval. These changes however, were statistically insignificant.

An average value of oxygen uptake (in ml per kg of body weight) during the 90–mins exercise (CET) has been found to be lower following ET and ETT (Table 2). Control group has shown a small increase of this parameter. Only the drop after ET (–2.43 ml x kg^{-1}) has shown a poor statistical difference ($p<0.005$). The differences between the effects of ET and ETT and the control group during CET-I and CET-II were statistically insignificant.

The exercise core temperature, measured at the end CET (Table 2) equal to 38.18°C before ET (CET– I) was diminished after training period (CET-II) to 37.87°C (DTre= –0.31°C). Similarly, exercise–thermal training (ETT) reduced the Tre from 38.01 to 37.85°C (DTre= –0.16°C). The above changes were statistically significant ($p<0.01$) the differences between the two protocols were significant. The values of

Table 2. Physiological responses to prolonged exercise in control and trained subjects. CG — Control Group, ET — Exercise Training, ETT — Exercise Thermal Training, N.S. — Statistically insignificant

Variable	Training				Variable	Training			
			Before	After				Before	After
VO_2max [ml × kg^{-1}]	CG	x	55.38	52.90	VO_2 [ml × kg^{-1}]	CG	x	31.90	32.49
		SD	6.45	4.21			SD	3.51	4.77
		t°	1.05				t°	0.66	
		p<	N.S.				p<	N.S.	
	ET	x	52.83	55.48		ET	x	31.07	28.64
		SD	7.45	10.06			SD	7.31	8.50
		t°	0.98				t°	2.24	
		p<	N.S.				p<	N.S.	
	ETT	x	55.08	56.69		ETT	x	30.28	29.05
		SD	7.82	7.05			SD	5.41	3.31
		t°	0.89				t°	1.08	
		p<	N.S.				p<	N.S.	
Tre [°C]	CG	x	38.22	38.16	Tm [°C]	CG	x	38.02	38.05
		SD	0.39	0.32			SD	0.47	0.36
		t°	1.22				t°	0.23	
		p<	N.S.				p<	N.S.	
	ET	x	38.18	37.87		ET	x	37.74	37.44
		SD	0.28	0.18			SD	0.30	0.53
		t°	4.71				t°	1.98	
		p<	0.005				p<	0.05	
	ETT	x	38.01	37.85		ETT	x	37.91	37.69
		SD	0.34	0.27			SD	0.34	0.28
		t°	2.88				t°	4.11	
		p<	0.01				p<	0.005	
Tsk [°C]	CG	x	30.92	31.07	VO_2 [ml × kg^{-1}]	CG	x	154	154
		SD	1.07	1.01			SD	14,7	12.7
		t°	0.43				t°	0.00	
		p<	N.S.				p<	N.S.	
	ET	x	31.13	30.5		ET	x	149	130
		SD	0.41	0.92			SD	13.4	13.6
		t°	1.58				t°	7.59	
		p<	N.S.				p<	0.001	
	ETT	x	30.82	30.10		ETT	x	145	135
		SD	1.19	1.22			SD	14.5	13.9
		t°	1.27				t°	8.4	
		p<	N.S.				p<	0.001	

Table 3. Absolute mean values and differences between individual groups of sweat rate (SR), plasma volume changes and (%ΔPV) during CET-I and CET-II.

Variable	Training			
			Before	After
Sweat rate [mg × cm × min^{-1}] [SR]	CG	x	0.581	0.516
		SD	0.39	0.29
		t°	1.261	
		p<	N.S.	
	ET	x	0.423	0.310
		SD	0.22	0.25
		t°	1.923	
		p<	N.S.	
	ETT	x	0.466	0.426
		SD	0.43	0.303
		t°	1.253	
		p<	N.S.	
%ΔPV	CG	x	–4.62	–4.13
		SD	4.4	4.8
		t°	0.275	
		p<	N.S.	
	ET	x	–8.05	+0.64
		SD	4.5	5.4
		t°	3.83	
		p<	0.01	
	ETT	x	–7.69	–5.61
		SD	7.13	5.9
		t°	0.81	
		p<	N.S.	
%ΔBwt rest-exercise	CG	x	1.51	1.48
		SD	0.44	0.31
		t°	0.39	
		p<	N.S.	
	ET	x	1.18	1.25
		SD	0.35	0.31
		t°	0.14	
		p<	N.S.	
	ETT	x	1.08	1.09
		SD	0.35	0.31
		t°	0.14	
		p<	N.S.	

Variable	Training			
			Before	After
Sweat rate [mg × cm × min^{-1}] [SR]	CG:ET	t°	1.107	1.681
		p<	N.S.	N.S.
	CG:ETT	t°	0.619	0.657
		p<	N.S.	N.S.
	ET:ETT	t°	0.500	1.267
		p<	N.S.	N.S.
%ΔPV	CG:ET	t°	1.72	2.07
		p<	N.S.	N.S.
	CG:ETT	t°	0.35	0.62
		p<	N.S.	N.S.
	ET:ETT	t°	0.51	0.61
		p<	N.S.	N.S.
%ΔBWT	CG:ET	t°	2.20	1.58
		p<	N.S.	N.S.
	CG:ETT	t°	2.46	2.67
		p<	N.S.	N.S.
	ET:ETT	t°	1.37	1.08
		p<	N.S.	N.S.

Tre in control group before and after the ten days interval (38.22°C — before and 38.16°C after) were almost the same. However, the end-exercise Tre values differ significantly between control group and the other two procedures.

The end-exercise level of v. lateralis muscle temperature tended to decrease after both types of training measured during CET-II and showed no changes after the ten days interval in control group (Table 2). Comparison of results among separate groups after training showed the statistically significant differences between ET and ETT as compare to controls but no differences were found between the training procedures.

Mean skin temperature (Tsk) has been found to decrease during CET (Table 2). Both types of physical training caused the further diminution of mean skin temperature during CET-I and CET-II) exercise of about –0.63°C and –0.72°C after ET and ETT respectively. The comparison of levels of Tsk at the end of CET performed before (CET-I) and after the training session (CET-II) showed the statistically insignificant differences. Control group did not show any valid distinctions (Table 2) as well as no differences between particular groups were obtained.

The above described changes resulted in an elevated gradient of rectal – skin temperature (DTre – Tsk) during CET–II performed after both training periods. Only the values in ETT were close to the statistically significance ($t^{o}=2.06$, $p<0.05$). The comparison of particular procedures with each other did not show any statistically significant differences.

Both types of training programmes significantly lowered ($p<0.01$) heart rate after the long-lasting exercise test (Table 2). Changes of heart rate (HR) as an effect of ET and ETT were statistically insignificant but they differed significantly as compared to control group. Furthermore control group did not show any significant distinction before (CET-I) and after (CET-II) the 10-days interval (Tab. 2).

The exercise training (ET) affected significantly the reduction in plasma volume ($p<0.01$). The changes of plasma volume reached from –8.0% to +0.6%. The levels of %DPV in the other protocols (ETT and control) as well as the comparison between particular training procedures (ET and ETT) and control groups showed the values being no statistically different (Tab. 3).

Similarly the intensity of sweating have shown to be lower after both types of training especially in the end part of CET-II (Tab. 3). However, we were not able to find any differences between applied training programmes and control group.

The total body water loss, expressed as %DBwt showed no statistically significant differences as an effect of both training programmes and after 10-days interval in control group. The lowest, body dehydration, was noted in the ETT protocol (Tab. 3). But the comparison of separate groups with each other marked differences we found only between control group and training procedures before training period (CET-I) as well between CG control groups) and ETT after training (CET–II).

In our studies the lower rectal temperature during control exercise test (CET-II) after both training programmes was observed. From some data (Saltin et al 1966) we have known that levels of rectal and oesophageal temperatures in different subjects are the same in relative work load, i.e. the percent of VO_2 max and various in relation to absolute values in work intensity. Therefore we may suppose that the apparent decrease of relative work-load (%$VO_{2\ max}$), it means the diminution of the level of exercise oxygen uptake, could be responsible for the observed decrease in rectal, muscle and skin temperatures and heart rate during post–training CET-II proving no improvement of exercise thermoregulatory responses themselves took place.

As we may see the reduction of exercise level of Tre during CET-II after ETT was high as 48% as compared to the diminution of rectal temperature after exercise training. However if we took into account the parallel average decrease of exercise oxygen uptake following ETT (CET-II) equal to 49% of reduction of VO_2 after exercise training the effect in thermoregulation seems to be true and can be considered as even the same in ET and ETT. It was confirmed by the insignificant differences between the levels of Tre after ET and ETT programmes. However, the dissimilarity in rectal temperature between ET and ETT on one hand and the control group an the other were statistically significant. Therefore we may concluded that the effect of both training programmes could be assumed as even the same despite of the marked differences in the duration of particular training unit.

Both types training procedures caused the lowering of mean skin temperature during CET-II (of about –0.63°C and –0.72°C after ET and ETT, respectively). Similar changes has been noticed in acclimatized and acclimated men by several authors (Astrand & Rodahl 1986, Fortney et. Al.1979, Frisancho 1979, Houdas et al. 1972, Ohnuki et al. 1982, Rowel 1974, Young et al. 1995). Because the parallel diminution of the level of rectal temperature was lower than of Tsk the gradient of temperature between the core and skin was increased during CET-II but only after ETT procedure and thus facilitated the dissipation of heat (Frisancho 1979).

The changes in m. vastus lateralis temperature were very similar to those of skin and rectal temperatures proved the level of Tmusc being lowered after training of thermoregulatiry functions. The same changes of oesophageal and rectal temperatures were found out after the ingestion of fluid during exercise (Kubica et al. 1986, Kubica et al. 1996, Montain & Coyle 1993, Żuchowicz et al. 1998). In controls no changes were observed.

The level of heart rate is commonly accepted as an important index of intensity of muscular work but could also together with the level of rectal temperature indicate the degree of acclimatization to heat (Kubica et al. 1996, Avellini et al.1982, Harrison et al.1981, Wyndham et al. 1970, Tyka et al. 1995). The lowering of heart rate after both training procedures may indicate the more economical function of cardiac muscle during prolonged exercise being accompanied by the lower end–exercise levels of muscle and rectal temperature as well as by the more effective heat loss (lower Tsk) through the skin surface area (Astrand & Rodahl 1986, Mitchell et al. 1976, Wyndham et al. 1964 a, Wyndham et al. 1964 b). As we remember the control group did not show any changes of HR after ten days interval but the statistically significant differences of values during CET-II after ET and ETT programs were noticed.

According to several authors an expansion of plasma or blood volume is observed in the initial period of acclimatisation (Fortney et al. 1979, Frisancho et al. 1979, Mitchell et al. 1976, Senay 1972, Senay et al. 1976). Some of them (Fortney et al. 1979) found out that physical training caused a significant expansion of resting plasma volume and total protein content while acclimatization caused increased sweating rates and decreased skin temperatures. The results of our studies indicated the significant lowering of post–exercise changes in plasma volume after physical training (ET) and a diminution of plasma volume statistically insignificant following exercise-thermal training (ETT). The %DBwt loss after that training was significantly different than in control subjects.

The statistically insignificant lowering of sweating rate during the end part of control exercise test after both kinds of training (CET-II) was compatible with the suggestion of Frisancho (Frisancho et al. 1979) that the maintenance of high sweating rate during acclimatization to heat was not an efficient mechanism adequate to keep the thermal balance.

Thus the better index noted very often seems to be the decrease of sweating rate and skin temperature during exercise performed after thermoregulatory improvement period and keep them at the level suitable to evaporate the necessary amount of sweat to maintain thermal homeostasis. However, some authors (Astrand & Rodahl 1986, Mitchell et al. 1976) described an increased sweat production in acclimatized person with the lowering of skin temperature threshold for the onset of sweating and others (Frisancho et al. 1979, Wyndham et al. 1964 a, Wyndham et al. 1964 b, Wyndham et al. 1964 c) wrote about the decrease of sweating rate but especially during physical exercise performed in those conditions.

Recapitulation and Conclusions

Based on this study we are able to conclude that physical training performed in warm environment (33°C ± 1°C, 50% of relative humidity) did not significantly affect the level of maximal oxygen uptake nor the (average) oxygen uptake during prolonged exercise test (CET). In other words this training program did not cause any changes in the level of oxygen metabolism during exercise. This was probably due to the relatively short training units.

Despite of the lack of any changes in oxygen metabolism i.e. in heat production the improvement of thermoregulatory responses could be observed. It was expressed

by a lower level of rectal, muscle and mean skin temperatures as well as heart rate at the end of prolonged 90 mins exercise (CET-II) on bicycle ergometer performed after ten days of exercise or exercise-thermal training. Finally, it should be emphasized that the last kind of training with shorter training units gave the very similar results in exercise thermoregulation as the exercise training program, but is more sparing in utilisation of energy sources.

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